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Global Scale Diagnoses of FGGE Data

a) Objectives

Our research objective has been to perform descriptive global-scale diagnoses of the GLAS FGGE SOP-1 analyses and to compare these diagnoses against controlled, real-data integrations of the GLAS GCM as well as other data sets. Specifically, we are:

- 1) Studying the effects of critical latitudes;
- 2) Diagnosing the influence of tropical wind data and latent heating upon the GLAS GCM;
- 3) Investigating planetary wave structure on various time scales from the diurnal to the monthly;
- 4) Comparing the GLAS analyses with other analyses.

b) Significant accomplishments

Our prior SOP-1 diagnoses (Paegle and Baker, 1982a, 1982b) suggest the following conclusions regarding global-scale waves:

- 1) Because the divergent component of the meridional flow is not much smaller than the rotational component, the global-scale structures resemble forced rather than free modes of linear theory.
- 2) The vertically reversing structure indicates that longitudinal heating gradients are probably important components of the forcing.

Short-term controlled GLAS GCM integrations (Baker and Paegle, 1983, Paegle and Baker, 1983) have shown that:

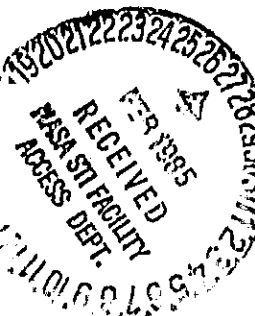
- 3) The inclusion of tropical wind data in real data integrations of the GLAS GCM has an important influence in the mid-latitude prediction in both hemispheres.
- 4) The tropical divergent wind reacts almost immediately to alteration of the tropical latent heating, while the rotational wind reaction requires several days. Furthermore, the presence or absence of zonally averaged easterlies depends strongly upon the presence of tropical latent heating.

c) Current research

The above results have provided direction for our current research. In particular, in order to advance our understanding of how much of the long-wave structure is a consequence of tropical latent heating, it is necessary to describe the full latent heating fields in some detail. Fortunately, the GLAS SOP-1 analyses contain estimates of the heating. As a preliminary check of the reliability of these fields in the tropics (where latent heating may account for the strongest heating rates) we have compared GLAS heating analyses with independent precipitation observations.

Heating

Detailed agreement between the condensation heating implied by the precipitation rates and the GLAS estimates of the heating may not be expected because of the lack of precipitation data over the oceans, representativeness problems of station precipitation data, and the presence of other sources of heating. Nevertheless, the precipitation data does support latent heating rates than may locally exceed 20°C/day, in consistency with the largest heating estimates of GLAS analyses.



N85-18533

Unclas
63/47 17521

(NASA-CR-174356) GLOBAL SCALE DIAGNOSES OF
FGGE DATA Semiannual Report (Utah Univ.)
6 P HC A02/HF A01 CSCI 04B

These extreme heating rates should produce vertical velocities on the order of 10 cm/s (i.e. vertical motions of approximately 300 mb/day) according to scaling arguments applied to the thermodynamic equation. The vertical motions we have computed from the horizontal divergence fields are this strong.

Divergent and rotational winds

Strongly divergent, upper tropospheric outflow is observed at the perimeter of highly precipitating regions of the tropics. This outflow should connect smoothly to surrounding regions of relatively weak divergence, and the result is a superposition of rotational and divergent wind having rather differing origins.

It is of obvious interest to describe this superposition. One method of quantifying this mixture is to describe the relative magnitude of the divergent and rotational components of the total wind field that projects upon the long waves.

We have performed diagnoses from three different analyses (ECMWF, GLAS, GFDL) of the data which emphasize that the strongest divergent wind regions are resolved in different objective analyses of the raw data. The weaker divergent winds of the ECMWF analyses probably reflect the first guess initialization procedure that is based upon an adiabatic formulation. The GLAS analysis does not incorporate any explicit initialization balances. The rotational wind field is less sensitive to the initialization procedure.

The variation of the meridional divergent wind from 20°S to 20°N is about as great as is the variation of the rotational meridional wind in this tropical belt. The amplitude of each is about 10 m/s to this truncation. This is quite different than in the mid-latitudes where the divergent wind is only a few m/s and the rotational wind may be much larger than 10 m/s. We conclude that although the regions of pronounced divergence are rather restricted, their influence projects strongly upon the global scale wind pattern of the tropics. Furthermore, since the rotational and divergent wind components of the large scale waves are of similar amplitude, they are both approximately equally observable in the tropics, at least for the long wave components. This is distinct from the mid-latitudes where the divergent wind field is generally weak enough to be obscured by observational error.

Controlled integrations of the GLAS GCM (Paegle and Baker, 1983) from this initial state confirm the fact that the tropical divergent wind field is sustained almost totally by latent heating. This experiment also shows that the adjustment of the tropical divergent wind to the heating requires less than one day, while the rotational wind requires several days, suggesting a more rapid adjustment mechanism and more rapidly propagating modes associated with the former.

One possibility is that gravity waves may dominate the adjustment of the divergent wind. To the extent that this is correct, and to the extent that the divergent wind contributes to the total tropical wave field, it may be inappropriate to study latitudinal wave connections through the tropics purely in terms of quasi-rotational wave theory. Silva Dias and Paegle, (1984) have shown that gravity and Kelvin modes are the main contributors to the tropical divergence field in 3 week averages of ECMWF level III-b data sets.

Tropical data impact

One of the fundamental questions is whether tropical critical latitudes may trap tropical waves or merely be a response to the tropical wave sources. Our observational and modeling studies (Paegle and Baker, 1982b, 1983) suggest that tropical waves and the zonally averaged westerly flow increase and decrease simultaneously, making it difficult to assess cause-effect. To the extent that tropical easterlies do inhibit meridional wave propagation, we may expect less impact for mid-latitudes out of regions of tropical easterly winds than from regions of tropical westerly winds. With this motivation, Dr. Wayman Baker has performed a series of assimilation experiments during February 1979 that are initialized when critical latitudes for stationary Rossby waves were more commonly found than during January. In the first experiment all available tropical wind data were used between 20°S and 20°N. In the second experiment, the tropical wind data were retained in regions of westerlies and suppressed in regions of easterlies. In a third experiment, tropical wind data were retained in regions of easterlies and suppressed in regions of westerlies. Finally, all tropical wind data were withheld in a fourth experiment.

We have begun to analyze the results of these forecasts. It appears that the inclusion of tropical easterly winds only in the assimilation is more effective in simulating the initial state than is the inclusion of only tropical westerlies.

The larger tropical differences at 72 h for the westerly data retention case with respect to the easterly data retention case reflect the larger initial differences for this case. However, near the perimeter of the significant Northern Hemisphere influence (at about 44°N) the influence of tropical easterlies is about as great as is the influence of tropical westerlies.

These experiments do not support a major role for critical latitude trapping with respect to meridional propagations in this GCM. We now conjecture that the observed association of equatorial westerlies with enhanced tropical divergent flow is either coincidental or that the enhanced tropical wave sources produce the zonally averaged tropical westerlies. This question and the explanation of the modes of tropical-extra-tropical wave interaction remain to be clarified, and provide focus for our future research plans.

d) Future plans

Our immediate plans include:

- 1) Completion of the study of the tropical data impact on the GLAS GCM.
- 2) Description of the heating fields.
- 3) Projection of the FGGE data upon the normal modes of the primitive equations.
- 4) Comparison of the GLAS analyses with others.

Some progress in steps one and two has been reported here. The computer code for the normal mode decomposition has also been developed and is necessary to describe the relative gravity wave and Rossby wave projection upon the full field. The gravity wave projection is particularly influenced by analysis of the divergence, that shows fairly substantial differences between different analyses.

e) Journal publications

- Baker, W.E. and J. Paegle, 1983: The influence of tropics on the prediction of ultra-long waves. part I: Tropical wind field. Mon. Wea. Rev., 111, 1341-1355.
- Paegle, J. and W.E. Baker, 1982a: Planetary-scale characteristics of the atmospheric circulation during January and February 1979. J. Atmos. Sci., 39, 2521-2538.
- Paegle, J. and W.E. Baker, 1982b: Global-scale weekly and monthly energetics during January and February 1979. J. Atmos. Sci., 39, 2750-2759.
- Paegle, J. and W.E. Baker, 1983: The influence of the tropics on the prediction of ultra-long waves. Part II: Latent heating. Mon. Wea. Rev., 111, 1356-1371.
- Paegle, J., J.N. Paegle, and Y. Hong, 1983: The role of barotropic oscillations within atmospheres of highly variable refractive index. J. Atmos. Sci., 40, 2251-2265.
- Paegle, J., J.N. Paegle, and F.P. Lewis, 1984: Large-scale motions of the tropics in observations and theory. In press, Pure and Applied Geophysics.
- Kalnay, E., J. Paegle, and K.C. Mo, 1985: Large-amplitude, short-scale stationary Rossby waves in the Southern Hemisphere: Observations and their possible origin. Submitted to J. Atmos. Sci.
- Paegle, J., W.E. Baker, and J.N. Paegle, 1985: The analysis sensitivity to tropical winds in the global weather experiment. To be submitted to Mon. Wea. Rev.
- Paegle, J., W.E. Baker, and J.N. Paegle, 1985: The forecast sensitivity to tropical winds in the global weather experiment. To be submitted to Mon. Wea. Rev.

f) Technical publications

- Paegle, J.N. and J. Paegle, 1984: Selected comparisons of FGGE level III-b winds. FGGE newsletter #3, USC-GARP, NAS.
- Paegle, J. and J.N. Paegle, 1984: GLAS heating rate estimates for SOP-1. FGGE newsletter #3, USC-GARP, NAS.
- Paegle, J. and G.W. Sampson, 1984: Estimates of the weekly evolution of heating fields and available potential energy during SOP-1. FGGE newsletter #4, USC-GARP, NAS.

g) Conference publications

- Paegle, J., 1983: Longitudinally Asymmetric Heating and Ultra-Long Waves. Proceedings of the IAMAP-WMO Symposium on Maintenance of the Quasi-Stationary Components of the Flow in the Atmosphere and in Atmospheric Models, 1983.
- Paegle, J.N., F.P. Lewis, and J. Paegle, 1983: Observed and Modelled Long wave Patterns of the Southern Hemisphere. Proceedings of the First International Conference on Southern Hemisphere Meteorology, 1983.
- Kalnay, E. and J. Paegle, 1983: Large Amplitude Stationary Waves in the Southern Hemisphere: Observations and Theory. Proceedings of the First International Conference on Southern Hemisphere Meteorology, 1983.
- Baker, W.E. and J. Paegle, 1983: The Influence fo the Tropics Upon the Prediction of the Southern Hemisphere Circulation within the GLAS GCM. Proceedings of the First International Conference on Southern Hemisphere Meteorology, 1983.
- Paegle, J. and J.N. Paegle, 1983: Models of Inter-Hemispheric Wave Propagation. Proceedings of the First International Conference on Southern Hemisphere Meteorology, 1983.
- Paegle, J.N. and J.-D. Gu, 1984: Interaction of orography and heating for planetary scales. Proceedings of the International Symposium on Plateau and Mountain Meteorology, Beijing China, March 1984.
- Paegle, J.N., Z. Zhao, Y. Hong, and J. Paegle, 1984: Sources of flow variability in barotropic primitive equation models. Proceedings of the International Symposium on Plateau and Mountain Meteorology, Beijing, China, March 1984.
- Silva-Dias, P.L. and J.N. Paegle, 1984: The partition of energy associated with tropical heat sources. FGGE workshop, Woods Hole, July 9-22, 1984.
- Paegle, J., and J.N. Paegle, 1984: Selected comparisons of three FGGE level III-b data sets. Proceedings of the WMO Scientific Seminar on Global Diagnostic Studies based on data collected during the GWE, Helsinki, 28-31 August 1984.
- Paegle, J.N., J. Paegle, and Z. Zhao, 1984: Intercomparisons of 200 mb global wind fields from level III-b data sets. Proceedings of the Scientific Seminar on Progress in Tropical Meteorology as a Result of the GWE. Tallahassee, Florida, 8-12 October 1984.
- Paegle, J., 1985: Interactions between convective and large-scale motions over Amazonia. Proceedings of the International Conference on Climatic, Biotic and Human Interactions in the Humid Tropics: Vegetation and Climate Interactions in Amazonia, São José dos Campos, Brazil, February 25-March 1, 1985.

The following two papers were presented at the First Meeting of Principal Investigators of the USA-Brazil Cooperative Program in Meteorology: Studies of Convection over the Amazon River Basin and Interaction with Large Scale Circulations in Higher Latitudes, March 5-6, 1984.

Paegle, J.: A review of Charney's notes on Large-Scale Tropical Motions based on FGGE data.

Paegle, J.N.: Global integrations of barotropic models forced by mass sources and sinks.

h) Theses and Dissertations

Ahrens, G., 1984: Characteristics of Precipitation Regimes During FGGE. Master's thesis, University of Utah, December 1984.

Robl, E., 1984: Planetary-Scale Barotropic Spectral Model. Ph.D. dissertation, approved on August 17, 1984.

Dodd, G.C., 1984: On the Transient Kinetic Energy of the Tropics. Ph.D. dissertation, approved on November 29, 1984.